



The DVB satellite, cable and SMATV systems

Why the technical choices were made

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1. Introduction

The digital broadcasting systems that have been defined by the Digital Video Broadcasting (DVB) Project represent a family of baseline specifications which match the characteristics of the delivery medium for which each system has been produced. Certain trade-offs have been made in order to develop the optimum solution, not only from the technical point of view but also from the commercial viewpoint. This is considered by the broadcasting community as one of the key successes of the DVB Project: the technical solutions are driven by market requirements. Thus, the various DVB systems satisfy the technical, operational and commercial requirements of the particular transmission network (satellite, cable, terrestrial) for which they have been designed, while keeping a high level of commonality between them; any “peculiarities” are restricted to those aspects of the system which are network-dependent.

The author describes the DVB systems that have been defined for the digital distribution of television, sound and data services via satellite, cable and SMATV networks.

Reasons are given for why the technical choices were made and the author briefly discusses future trends in digital broadcasting, especially the move towards interactive broadcasting.

A complete family of specifications has been produced by the DVB consortium. Each DVB system is, at the same time, flexible enough to satisfy specific requirements for the implementation of a specific service.

Now that the DVB broadcasting systems have been defined, a further step towards interactive services is being undertaken, thus enabling the current capabilities of the DVB systems to be upgraded.

Original language: English
Manuscript received 26/10/95.

2. European DVB requirements

The DVB family of systems has been produced according to a set of commercial requirements, which have then been used to check the technical specifications in order to define the practical systems for users and manufacturers.

Among the most relevant issues taken into account when developing the DVB baseline specifications are the following:

- the source coding, framing and multiplexing should use only MPEG-2;
- there should be maximum commonality within each medium and between media;
- the target retail prices for direct-to-home (DTH) consumer equipment should be less than 600 ECUs at the introduction phase (1995) and less than 350 ECUs within 2 years of introduction;
- the target price for head-end equipment in Satellite Master-Antenna Television (SMATV) applications should not exceed 2500 ECUs at the introduction phase and less than 1500 ECUs within 2 years of introduction;
- the transmission system should accommodate the 4:3, 16:9 and 2.21:1 picture formats;
- the audio source coding should be MPEG layer II (MUSICAM);
- the Integrated Receiver Decoder (IRD) should provide facilities for “fast channel hopping” and the service acquisition time for all services should be less than 0.5 seconds;

It should be noted that, following the definition of the DVB baseline specifications and the adoption of them by ETSI¹, the first commercial services started in 1995. Furthermore, extensive tests have been carried out within the Euro-Image Project² in order to assess how well DVB-specified equipment (transmitters and receivers) works in prac-

1. European Telecommunication Standards Institute.
 2. The Euro-Image Project was set up to study the performance of DVB systems for satellite and cable delivery, and the Service Information aspects. Coordinated by the EBU, it was partially funded by the European Commission.

tice. Those tests have confirmed the performance expected of DVB-specified equipment, thereby supporting the technical choices that were made when defining the architecture and normative requirements (ETSI standards) of the DVB systems [1], [2], [3].

3. DVB broadcasting systems

The overall architecture of the DVB systems is shown in *Fig. 1*.

The function of each block is as follows:

1) Source coding and multiplexing

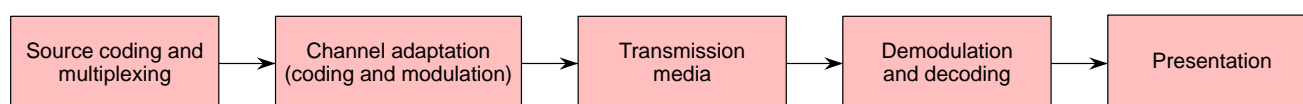
This block provides the tools to compress the digital vision and sound signals to the rate required by the data stream which, in turn, depends on the specified quality of the television signal. This process allows a reduction of the bandwidth needed.

DVB has adopted *MPEG-2* [4] as the tool-box from which to make up systems which incorporate greater or lesser degrees of sophistication. The DVB recommendations on how to implement MPEG-2 are described in [5] and general background information is provided in [6]. From a commercial viewpoint, MPEG-2 was identified as the best candidate because of its capacity to provide maximum commonality among different transmission media – particularly satellite, cable, SMATV and terrestrial – and its capacity to permit flexible Service Information (SI) for all configurations of services and service components, including television, sound and data.

The MPEG-2 multiplex system was chosen by the DVB Technical Module (DVB-TM) which took into account, among other things, the following features:

- its packet structure, which provides efficient system synchronization and enables the assembly of all the components in a single bit stream;
- it is suitable for recording purposes at the receiver since the bit stream includes its own presentation mechanism;
- it is the system which best covers the requirements of the different transmission media (satellite, cable, terrestrial, etc.).

Figure 1
Overall architecture of the DVB system.



2) Channel adaptation

This block helps to facilitate the transmission of the MPEG-2 Transport Stream (MPEG-TS) over the specific delivery medium. It is necessary to adopt particular modulation and coding schemes to ensure that the signal is matched to the channel environment. Depending on the channel characteristics, either a more robust or a more spectrum-efficient modulation scheme may be optimum.

3) Transmission media

The transmission media can be based on delivery by satellite, cable, SMATV or terrestrial transmitters (UHF or microwave). Each one has its own physical properties which have been considered in the development of the DVB systems. Obviously, the DVB Project does not specify particular requirements for the transmission medium, but the transmission channel characteristics have duly been taken into account to ensure that reception of the MPEG-TS is virtually free of errors. The concept utilized by DVB is based on *quasi-error-free*³ (QEF) reception of the MPEG-TS signal.

4) Demodulation and decoding

These functions are implemented in the receiving chain in order to acquire the baseband signal (i.e. the MPEG-TS) and to remove the RF signal carrier. It is important that the receiver takes into account any variations in the channel responses (amplitude and group delay) with time and under particular conditions.

Digital signals are sensitive to echoes present in the channel. To cope with this, equalization techniques are available when needed to compensate in an adaptive way for the most relevant channel distortions.

5) Presentation

The display formats (i.e. aspect ratios) required by DVB are 4:3, 16:9 and 2.21:1. These formats should preferably be transmitted with the full number of active lines. To enable a transmitted format to be displayed on a television set that is designed to receive a different display format, the DVB system transmits dynamic “pan” vectors.

4. The DVB-S system for satellite broadcasting

As the source video and sound coding are based upon the MPEG-2 Transport Stream, the DVB family of systems places specific emphasis on the optimization of the channel coding and modulation schemes.

The DVB satellite system (DVB-S) has been defined for the broadcasting and distribution of digital multiprogramme television and HDTV services in the Broadcast Satellite Service (BSS) and the Fixed Satellite Service (FSS) bands⁴. The DVB-S system is also intended to provide Direct-To-Home (DTH) services for consumer Integrated Receiver Decoders (IRDs), as well as Satellite Master-Antenna Television (SMATV) systems and cable (CATV) systems where the DVB signals need to be remodulated for distribution purposes.

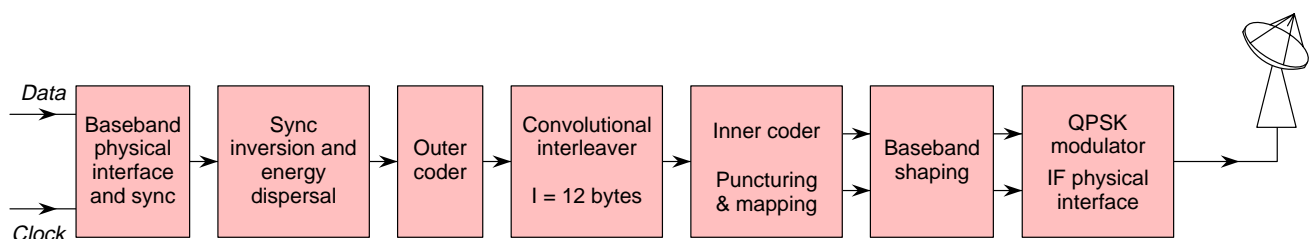
The DVB-S system is suitable for use on satellites whose transponder bandwidth lies within the range 26 MHz to 54 MHz. Current European satellites which can carry the DVB-S signals include Astra, DFS, Eutelsat, Hispasat, TDF, Telecom, Tele-X and Thor.

By using a time-division-multiplex (TDM), a variety of digital vision, sound and data services can be superimposed onto a single RF carrier in the transponder. The number of different services which can be multiplexed onto the carrier is a function of the television picture quality required and the marketing strategy of each broadcaster.

Figure 2
DVB satellite
transmission system.

3. QEF reception means that less than one uncorrected error-event-per-hour should be presented to the MPEG decoder.

4. FSS downlink band = 10.7 – 11.7 GHz
12.5 – 12.75 GHz
BSS downlink band = 11.7 – 12.5 GHz.



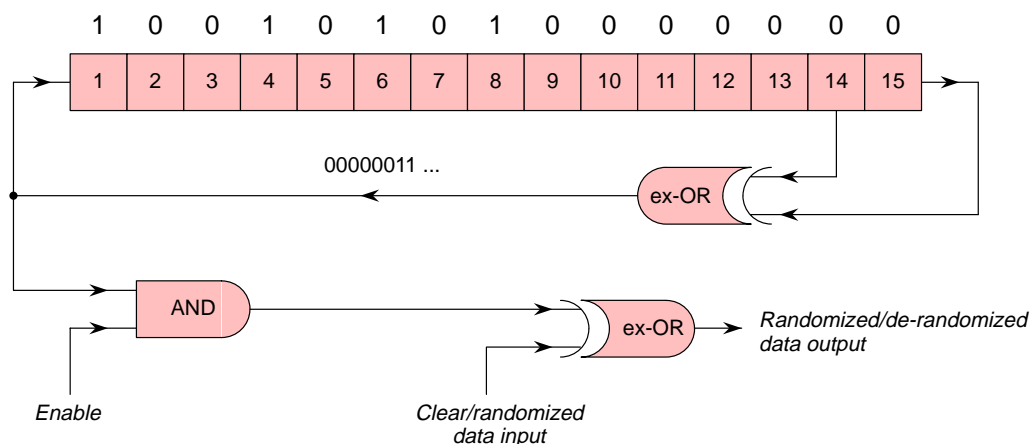


Figure 3
Randomization process.

In the case of TDM, the satellite can be operated at saturation since there is only one carrier in the transponder. However, an alternative multi-carrier system called *frequency-division multiple access* (FDMA) can be used for satellite delivery. In this case, it is necessary to operate the satellite transponder with an *output back-off* (OBO) in order to limit the level of the intermodulation products.

The total power available from a given transponder to each carrier, taking into account the required OBO, is lower than in the TDM case. Consequently, the bit energy (E_b) value for each carrier and the link budget margin are reduced. Furthermore, taking into account the bandwidth resources in the transponder, the total capacity is lower in the case of FDMA because of the need to keep guard-bands between the carriers.

One advantage of FDMA technology is that it allows the possibility to uplink signals to the same transponder from different sites, thus avoiding the need to transport all the TV programmes to one particular site. It is interesting to note that the European Space Agency is in charge of a new project called SKYPLEX which aims to find ways of compensating for the OBO required when using the FDMA system. This project will develop ground-based equipment and some intelligent on-board processing in the satellite to create a multiplex capability at the spacecraft; the downlink will be a TDM single-carrier system with the satellite transponder operating at saturation point, while the uplink will be a multi-site mixture of several carriers.

4.1. DVB-S transmission chain

A schematic diagram of a DVB-S transmission system is shown in Fig. 2. The source signals have to be adapted to the characteristics of the satellite channel and, therefore, they are processed in the following ways:

1) Transport multiplex adaptation and randomization for energy dispersal

The input bit stream has to be organized in fixed-length packets (188 bytes) according to the MPEG-2 Transport Stream. One of these bytes is a synchronization word; there are also three header bytes in the stream and the remaining bytes contain the information data.

In order to ensure adequate binary transitions, a randomization process has to be applied to the data (see Fig. 3). The shift register is initiated by the sequence at the start of every eight transport packets. In order to ensure the initialization sequence for the descrambling process, the MPEG-2 sync byte of the first packet is bit-wise inverted.

The randomization process has to be active to avoid the emission of an unmodulated carrier. The spectrum spreading which results from the use of the scrambling process is shown in Fig. 4.

2) Outer coding

This is applied in order to produce an error-protected packet. A shortened Reed-Solomon (RS) code is applied (type 204,188) with the ability to correct eight random byte errors.

3) Convolutional interleaving

This is based on the Forney convolutional approach with $I = 12$. Although more complicated to produce, the convolutional type of interleaver requires about half the chip implementation area (and hence, half the memory) required by a block interleaver, without any reduction in performance.

4) Inner coding (convolutional)

This function allows the use of a flexible code rate in order to choose the most convenient level

of error correction for each service or bit-rate. It is based on the well-known *puncturing* technique, usually included in commercially-available Viterbi decoders. The code rates can be 1/2, 2/3, 3/4, 5/6 and 7/8. This flexibility allows the user bit-rate to be optimized according to the available satellite EIRP, receiving antenna size and service availability targets.

After detailed trade-offs between complexity and performance, the DVB Project has adopted a constraint length of $K = 7$, which corresponds to 64 states. Compared with another option studied ($K = 6$) and for a fixed puncturing rate, the coding gain with a constraint length of $K = 7$ is higher, although it was noted that the convolutional code with a constraint length of $K = 6$ is less complex.

The received signal is also corrupted by *additive white Gaussian noise* (AWGN). Thus, a powerful error-correcting scheme is needed to achieve a QEF link with low carrier-to-noise (C/N) ratios. This is achieved by means of an inner convolutional code, concatenated with an outer Reed-Solomon code. A “soft decision” Viterbi decoder is used to decode the inner code. Because of its intrinsic behaviour, error bursts appear at the output of the Viterbi decoder. These are broken up by using a symbol deinterleaver which splits them into isolated or small manageable bursts of erroneous bytes which can be corrected by the outer Reed-Solomon decoder.

The performance and complexity of this system are mainly influenced by three parameters:

- the number of states of the convolutional code;
- the rate of the convolutional code;
- the error-correcting capability of the Reed-Solomon code.

Although the system is complicated, it has the ability to correct errors in an optimum way; by sharing the task between the RS decoder and the Viterbi decoder, the overall system complexity is minimized.

5) Baseband shaping of the signal pulse

A transmission roll-off factor of 35 % has been selected, following extensive studies and computer simulation analysis.

6) Modulation

With the aim of allowing the receiver to detect the signal adequately at very low C/N ratios, a relatively-simple channel modulation scheme has been adopted: *quaternary phase shift keying* (QPSK). This scheme has a constant envelope amplitude and widely-separated phase states, which give a high degree of ruggedness against channel noise and interference. QPSK allows the satellite travelling-wave tube amplifier (TWTA) to operate at saturation and the losses are less than 1 dB. Also, QPSK is a very mature solution which is widely used in professional applications, and is also suitable for the consumer market because of its ruggedness when subjected to synchronization inaccuracy. The encoded digital symbols are processed by a conventional Gray-coded QPSK modulator, which provides absolute mapping at the desired frequency.

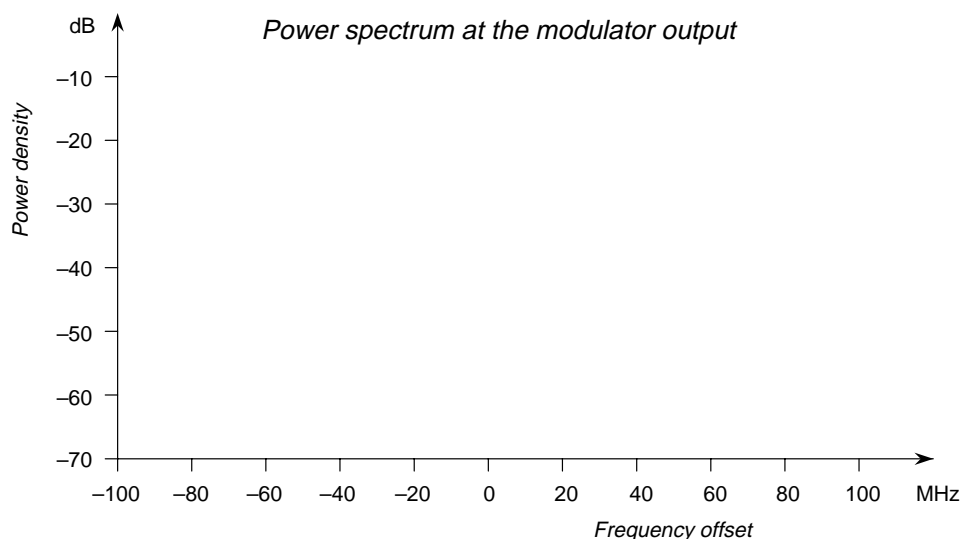


Figure 4
Effects of scrambling
on the spectrum
shaping.

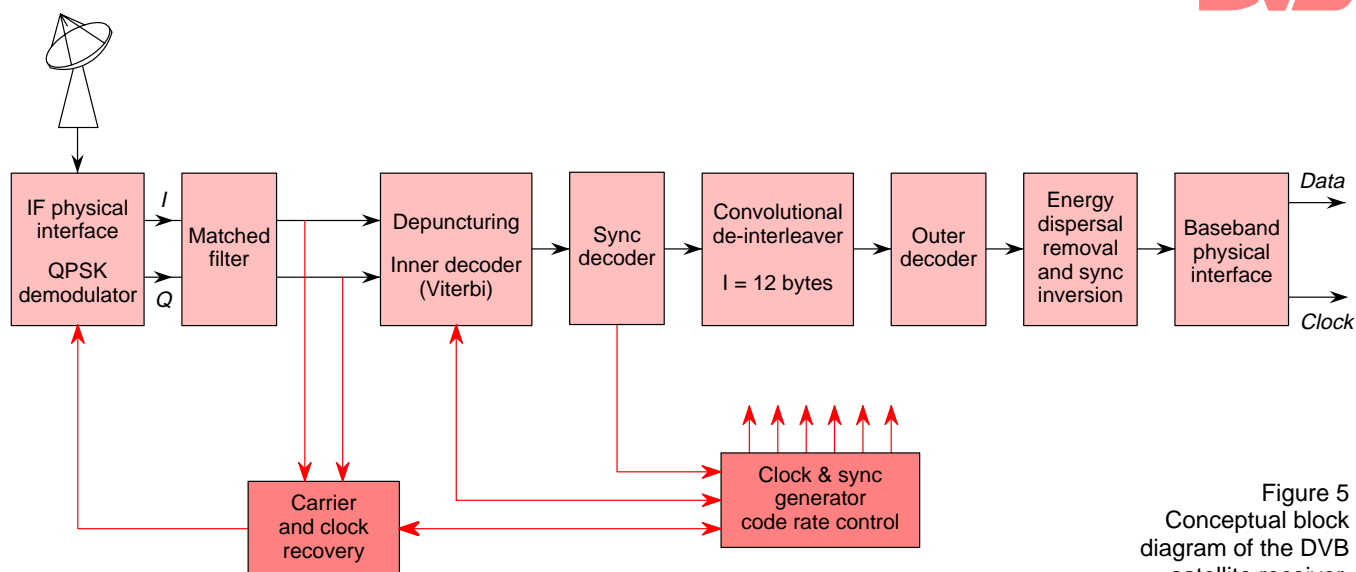


Figure 5
Conceptual block
diagram of the DVB
satellite receiver.

4.2. DVB-S receiving chain

The receiving chain uses similar functional blocks to those used in the transmitting chain. The main receiving functions are as follows (see Fig. 5):

1) IF interface and QPSK demodulator

This unit performs the quadrature-coherent demodulation function, the analogue-to-digital conversion and provides soft-decision I and Q information to the inner decoder.

2) Matched filter

This unit performs complementary pulse-shape filtering, of the raised cosine type, according to the roll-off of 35% in the transmitting chain. A finite impulse response (FIR) digital filter can be used to provide equalization of the linear channel distortions in the IRD.

3) Carrier/clock recovery unit

This device recovers the demodulator synchronization. The probability of loss of synchronization over the full C/N range of the demodulator should be very low.

4) Inner decoder

This unit performs first-level error-protection decoding. It should operate at an input-equivalent “hard decision” bit-error-rate (BER) in the order of 10^{-1} to 10^{-2} (depending on the adopted code rate), and should produce an output BER of about $2 \cdot 10^{-4}$ or lower. This output BER corresponds to a QEF service after outer code correction. This unit can also make use of “soft decision” information; it evaluates each of

the code rates and puncturing configurations until “lock” is acquired. Furthermore, it can resolve $\pi/2$ demodulation phase ambiguities.

5) Sync byte decoder

This decoder provides synchronization information for the de-interleaving process. It can also resolve any ambiguities arriving from the QPSK demodulator (which were not detected by the Viterbi decoder).

6) Convolutional de-interleaver

This component allows the error bursts arriving from the inner decoder to be randomized on a byte basis, in order to improve the burst-error-correction capability of the outer decoder.

7) Outer decoder

This unit provides second-level error protection. It can provide QEF output (i.e. with a BER of about 10^{-10} to 10^{-11}) in the presence of input error bursts at a BER of about $7 \cdot 10^{-4}$ or better with infinite byte interleaving. In the case of an interleaving depth of $I = 12$, a BER of $2 \cdot 10^{-4}$ is assumed for QEF decoding.

8) Energy dispersal removal

This component recovers the user bit-rate by removing the randomizing pattern used for energy dispersal purposes, and changes the inverted sync byte to its normal MPEG-2 value.

9) Base-band physical interface

This component adapts the data structure to the format and the protocol required by the external interface.



Table 1
Examples of useful
bit-rate capacity.

Transponder bandwidth (MHz)		Typical symbol rate (Mbaud)	Useful bit-rate capacity (Mbit/s)				
-3 dB	-1 dB		Code rate 1/2	Code rate 2/3	Code rate 3/4	Code rate 5/6	Code rate 7/8
54	48.6	42.2	38.9	51.8	58.3	64.8	68.0
46	41.4	35.9	33.1	44.2	49.7	55.2	58.0
40	36.0	31.3	28.8	38.4	43.2	48.0	50.4
36	32.4	28.1	25.9	34.6	38.9	43.2	45.4
33	29.7	25.8	23.8	31.7	35.6	39.6	41.6
30	27.0	23.4	21.6	28.8	32.4	36.0	37.8
27	24.3	21.1	19.4	25.9	29.2	32.4	34.0
26	23.4	20.3	18.7	25.0	28.1	31.2	32.8

4.3. Exploitation of the transponder bandwidth

The most important feature of the DVB-S system is its flexibility to accommodate a wide range of possibilities: useful bit-rate, forward error correction (FEC), transponder bandwidth, etc. *Table 1* gives examples of the useful bit-rate capacity (R_u) achievable on a satellite transponder with a bandwidth (BW) corresponding to a $BW/R_s = 1.28$, where R_s is the transmission symbol rate.

Other BW/R_s values may be adopted for different service requirements, depending on the trade-off implemented between the transmission capacity and the bit-energy-to-noise-density ratio (E_b/N_0).

Flexibility is one of the remarkable achievements of the DVB-S system (also applicable to the DVB-C and DVB-SMATV systems). No specific bit-rates or FEC code rates have been established and the concept of variable-symbol-rate receivers – with the ability to identify the transmitted FEC rate – constitutes the real advantage of DVB to serve the market needs.

4.4. Antenna size

During the process of developing the DVB-S system, attention was paid to the antenna size required to receive the transmissions in simple DTH applications. To compute the required antenna size, it is necessary to know the E_b/N_0 that is needed by the demodulator to ensure a BER of better than $2 \cdot 10^{-4}$ (QEF conditions) after Viterbi decoding. The C/N can then be derived and finally, the required antenna gain (and hence its size).

Figs. 6 and 7 illustrate some examples of the relationships between these parameters. For example,

with reference to *Fig. 6*, for a bit-rate of 29 Mbauds and a code rate of 2/3, the required antenna size is about 60 cm, assuming a service availability of 99.7% (average year) in rainfall zone K.

Note the impact that a symbol rate increase has on the required antenna size. It is thus convenient to make a trade-off between the required antenna size and the symbol rate for each service.

Fig. 7 shows the relationship between service availability and useful bit-rate, as a function of the antenna size. For a useful bit-rate of 38.9 Mbit/s with an FEC code rate of 3/4 (corresponding to a symbol rate of 28.1 Mbauds) and an antenna size of 60 cm, a service availability (average year) of 99.9% is reached. Note again the relationship between the bit-rate and the antenna size. In this case, the bit-rate has been expressed in terms of useful bit-rate.

The Euro-Image Project has made a detailed analysis of the performance of the DVB-S system, by using it in real scenarios. Those results are reported in [7]. Among others, the following effects have been evaluated by means of software and hardware simulations, IF loops and real satellite transmissions. The results obtained confirm the suitability of the DVB-S system to work in real conditions with excellent performance.

1) Bandwidth limitation

This is the degradation due to the limited bandwidth of the transponder input multiplexer (IMUX) and output multiplexer (OMUX) filters, mainly the OMUX filter. It depends on the BW/R_s ratio and is around 0.4 dB for reasonable BW/R_s ratios.

2) Non linearities

Non-linearities in the transponder TWTA can cause intersymbol interference (ISI). The level of this interference depends on the TWTA operating point and is a maximum at saturation point. Typically, the degradation due to ISI lies in the range 0 to 0.7 dB.

3) Power reduction due to non linearities

This effect, which is different from intersymbol interference, is due to the appearance of secondary side lobes of the signal spectrum, caused by the non-linear behaviour of the TWTA and the filtering that the signal suffers at the OMUX. The power reduction due to this effect has been evaluated by computer simulations; it is around 0.9 dB when the TWTA is operating at saturation point.

4) Modem implementation margin

This is the difference between the theoretical performance and the real performance of modems working back-to-back. A value of 0.8 dB (as used in the DVB-S specification) has been taken as a reference. Real tests have confirmed this value for most of the cases.

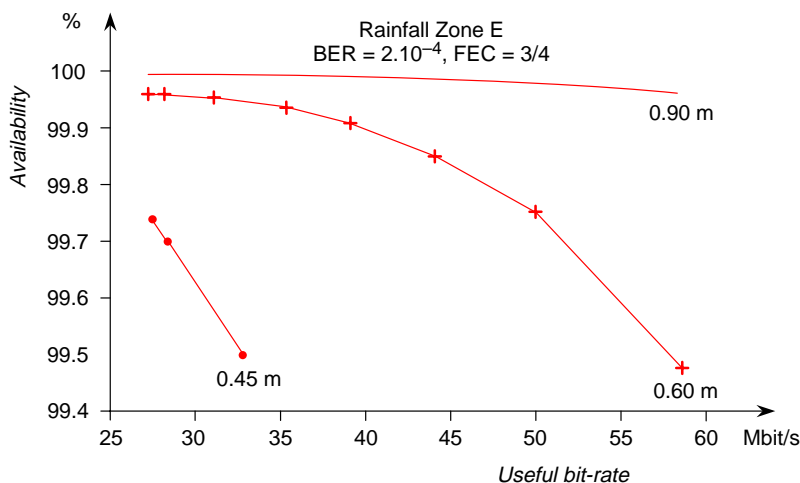
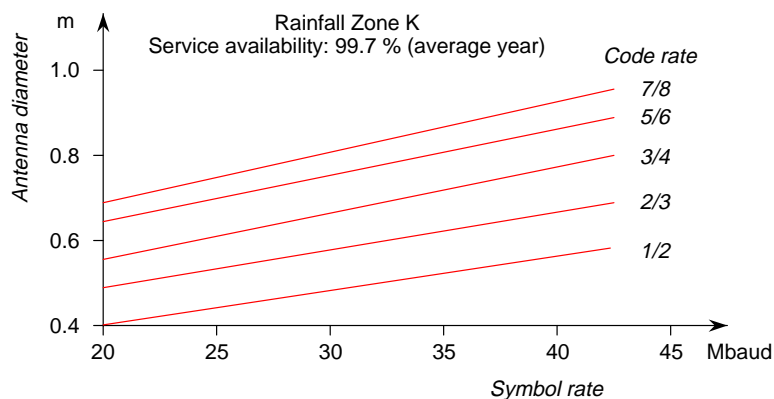
5) Noise bandwidth increase due to the outer code

The outer code causes the noise bandwidth of the signal, after decoding, to increase by a factor of $10 \log 204/188$ (i.e. around 0.36 dB).

This increase should be taken into account when using the E_b/N_0 that refers to the useful bit-rate before RS encoding has taken place.

The reference values to adopt when planning DVB-S services are detailed in *Table 2* (on the next page). They represent the most accurate assumptions for the performance of DVB-S equipment and have been obtained from the work carried out in the Euro-Image Project, coordinated by the EBU.

This table includes figures that can be assumed in the planning of DVB-S services to ensure their compatibility in terms of protection ratios (PR). It can be seen that, for a full digital scenario, a significant relaxation of the criteria is possible when compared with the current full analogue scenario. Values of about 16 dB for co-channel PR and 12 dB for adjacent channel PR are recommended. In the case of the hybrid digital/analogue scenario, the conclusions show that a value of about 23 dB for co-channel PR and



15 dB for adjacent-channel PR (half channel bandwidth overlapping) could be appropriate when a digital signal interferes with the analogue TV/FM signals. On the other hand, when an analogue signal interferes with a digital DVB-S signal, the recommended protection ratios decrease to 17 dB for co-channel PR and 13 dB for adjacent-channel PR.

In conclusion, the introduction of the DVB-S system will guarantee a better exploitation of the limited orbit-spectrum resources that are available for satellite broadcasting.

However, representations should be made to the appropriate regulatory and frequency planning bodies, to ensure that the assignments for digital broadcasting satellite services are consistent with the results obtained.

Figure 6 (upper)
Examples of antenna diameter versus symbol rate.

Figure 7 (lower)
Examples of availability versus useful bit-rate.

Parameter	Euro Image reference values (dB)
Bandwidth limitation degradation	0.1 – 0.4
Non linearities (ISI) degradation	0.0 – 0.7
Noise bandwidth increase $10\log(204/188)$	0.36
Interference losses (intrasystem)	0.0 – 0.3
Power reduction due to non linearities	0.9
Modem implementation margin	0.8
Distortion due to SMATV distribution network	
SMATV-S	1.00 – 1.85
SMATV-S equalized	0.25 – 0.50
SMATV-IF	3
Required E_b/N_0 AWGN (note 1)	
FEC 1/2	4.6
FEC 2/3	5.1
FEC 3/4	5.6
FEC 5/6	6.3
FEC 7/8	6.8
Required E_b/N_0 satellite (note 2)	
FEC 1/2	5.5
FEC 2/3	6.0
FEC 3/4	6.6
FEC 5/6	7.2
FEC 7/8	7.9
Protection Ratios:	
<i>Full Digital Scenario (BW/Rs = 1.28)</i>	
CCI	16
H-ACI (note 3)	12
<i>Hybrid Digital/Analogue Scenario</i>	
CCI, D-to-A	23
CCI, A-to-D	17
H-ACI, D-to-A	15
H-ACI, A-to-D	13

Note 1: The values of E_b/N_0 AWGN take into account the contribution from the modem implementation margin (0.8 dB) and the noise bandwidth increase ($10 \log (204/188)$).

Note 2: The required E_b/N_0 satellite values add the following contributions to the required E_b/N_0 AWGN: bandwidth limitation degradation and non linearities (ISI). Power reduction due to non linearities and intrasystem interference losses are not included in the required E_b/N_0 satellite values.

Note 3: H-ACI is adjacent channel interference from a signal which is half a channel width away (F-ACI is the case where the interfering signal is a full channel width away).

Table 2
Reference values to adopt when planning DVB-S services.

5. The DVB-C system for cable distribution

Cable television networks are normally structured like trees, with trunk routes, branches and sub-branches. In order to achieve cost-effective and reliable distribution of the television and sound programmes, coaxial cable and hybrid fibre/coaxial (HFC) technologies are used.

The DVB cable distribution system (DVB-C) is designed to be fed by a combination of satellite signals, local programme sources, and signals incoming from contribution links; the appropriate programme content is assembled from those sources at the CATV head-end. The signals arriving from a satellite will usually need to be demultiplexed at the head-end in order to insert them into the cable programme multiplex.

A block diagram of the DVB-C transmission chain is shown in Fig. 8. The most important characteristics of the DVB-C system are as follows (see also [8]):

- 1) Commonality with the DVB-S system in terms of coding, multiplexing, framing, interleaving, outer codes and variable symbol rates. This constitutes a noticeable step towards economies of scale and the transparency of signals passing through different networks.
- 2) The principal challenge in cable environments is the limited channel bandwidth (8/7 MHz). Although a cable channel is typically more complex than a satellite channel (because of the short-delay echoes and the intermodulation products which need to be taken into account), CATV networks represent a suitable medium for digital TV broadcasting.

The DVB-C system has been defined to make optimum use of the limited capacity available on the cable channel. Single-carrier modulation, using 16-, 32- and 64-QAM⁵ has been chosen, as it more-closely matches the characteristics of the cable channel than the other modulation schemes that were considered. Also, it offers lower sensitivity to interference and a 10% more useful bit-rate than these other schemes. Furthermore, the preference of the industrial manufacturers for QAM was taken into account when making this choice.

The QAM systems currently specified for DVB-C can be extended in the future to include a greater number of constellations (e.g. 128- and 256-QAM).

5. Quadrature amplitude modulation.

Baseband interface to:
 - local MPEG-2 programme sources
 - contribution links
 - remultiplexers, etc.

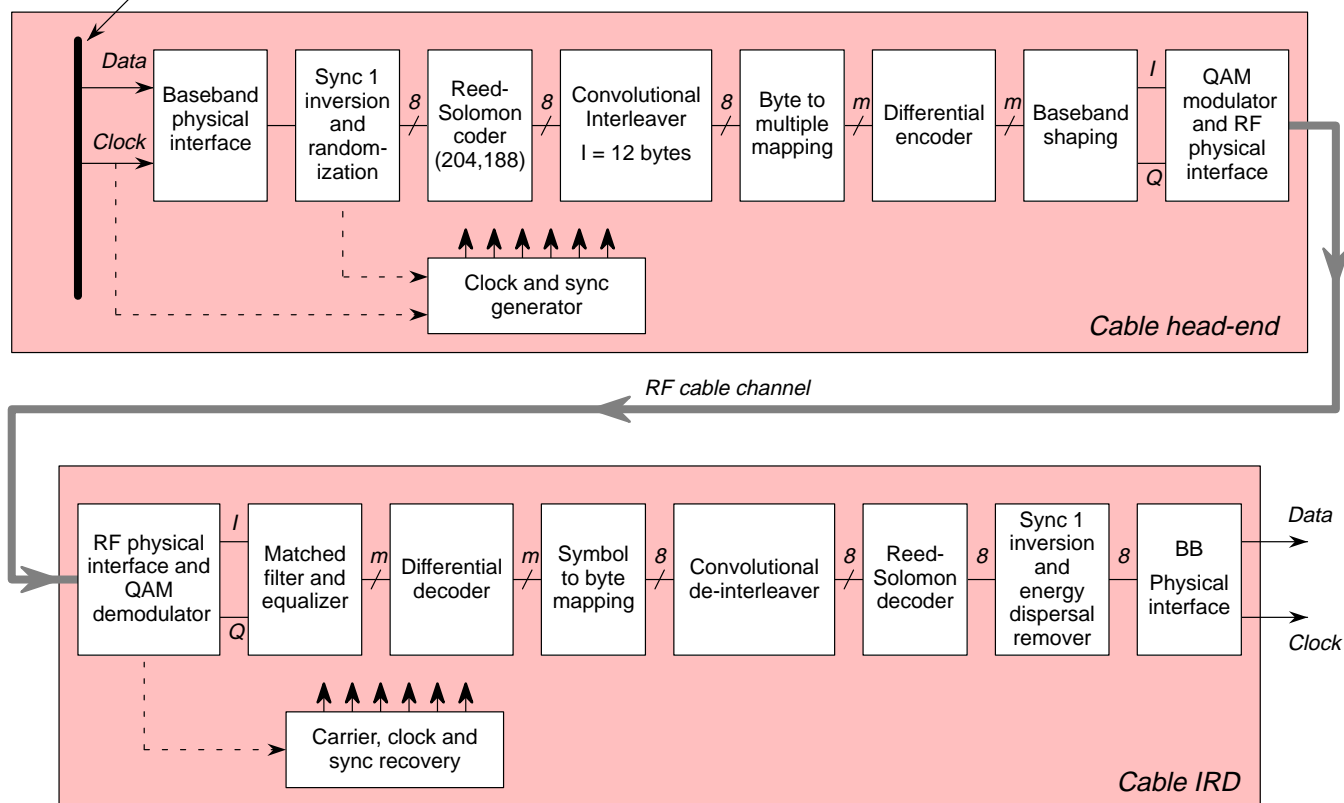


Figure 8
 Conceptual diagram
 of the main elements
 at the cable head-
 end and at the
 receiving site.

- 3) No convolutional inner code is needed. The rationale for taking this decision was based on the higher C/N ratios that are normally available on cable networks.
- 4) A roll-off factor of 15% has been specified for DVB-C, which is sharper than for the satellite system. It will allow the transmission bit-rate to be maximized in the cable channel, thus helping to achieve transparent distribution of an incoming satellite signal along the cable network.
- 5) At the very early stage of definition, it was thought that training sequences for the adaptive equalizers would be necessary, in order to achieve transient times of less than 50 ms in the cable network, and also to enable an extension of the modulation system to 128- or 256-QAM. However, based on theoretical considerations and practical computer simulations, it was concluded that both modulation options could be achieved with an optimized “blind” equaliza-

tion which does not include any training sequences⁶.

If training sequences should become a necessity for applications not foreseeable at this time, they could be incorporated in the MPEG-2 transport stream as *private data streams* which would require between 0.5 and 2% of the available capacity. In common with the other transport packets, care would need to be taken that these training sequence packets – in passing along the whole encoding chain (energy dispersal, RS coder, convolutional interleaver, etc.) – do not lose their training capabilities.

Table 3, which is taken from [9], shows the region of possible transmissions rates, the associated symbol rates and the occupied bandwidth for QAM with 16-, 32- and 64-state constellations.

6. A “training sequence” is a signal of fixed shape. The receiver adjusts its equalization until the shape is correct.

Transmission rate (Mbit/s)	Symbol rate (Mbaud)	Bandwidth (MHz)	Modulation
18.9 – 25.2	5.13 – 6.84	5.90 – 7.86	16-QAM
26.1 – 31.9	5.66 – 6.92	6.51 – 7.96	32-QAM
32.6 – 38.1	5.89 – 6.89	6.78 – 7.92	64-QAM

Table 3
Relationship between transmission rate, symbol rate, bandwidth and QAM constellations.

Notes: Roll-off factor = 15%
RS code = (204, 188, T = 8)
No inner code.

6. The DVB-SMATV system

Satellite Master-Antenna Television (SMATV) systems are intended for the distribution of television and sound signals to households in just one building or, perhaps, in a small number of closely-spaced buildings. The signals are received by a satellite dish antenna and may be combined with terrestrial television and radio signals. SMATV distribution systems are also known as *community antenna installations* and also as *domestic TV cable networks*. A SMATV system is a means of sharing the same resources for the reception of satellite and terrestrial signals among several users.

SMATV is the dominant TV distribution system in some European areas and it was desirable for DVB to define the baseline system for use with those

distribution networks. This has been done, in collaboration with the DIGISMATV⁷ project.

It should be stressed that SMATV is not strictly a small CATV; SMATV networks are an intermediate option between individual “direct-to-home” reception (DTH) and CATV as shown in Fig. 9. SMATV networks are always associated with the reception of satellite signals and use a cable network structure to distribute these signals transparently to a group of users, either using the original satellite modulation system or by using a different system that is more spectrally-efficient for cable distribution.

Digital SMATV systems are based on the concept established by the DVB-S satellite system [1] and the DVB-C cable system [2].

Two configurations have been defined [10] to distribute the digital satellite TV signals to users via analogue SMATV distribution systems:

1) Transparent transmodulation from QPSK to QAM signals

This configuration is known as *SMATV System A* in ETSI terminology [3]. The QPSK signal arriving from the satellite is demodulated, decoded and then re-modulated in QAM, in order to be allocated to a 8 MHz UHF cable channel.

7. The DIGISMATV project, partially funded by the European Commission, was set up to study the introduction of digital television in SMATV installations.

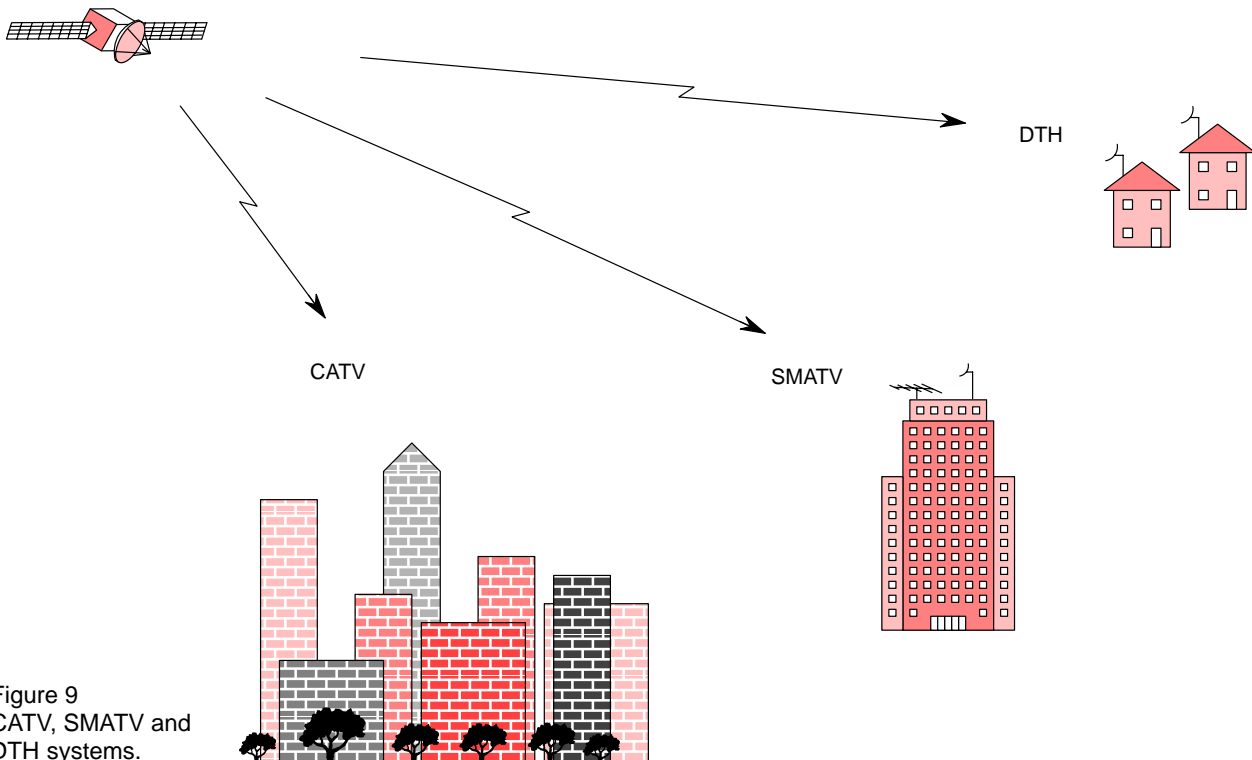


Figure 9
CATV, SMATV and DTH systems.

The key feature of this configuration – also known as *Digital Transmodulation* (SMATV-DTM) – is the *transparency* concept. This means that the contents of the satellite carrier are transferred directly to the cable carrier without demultiplexing or any other form of base-band processing. It thus permits the design of very cost-effective head-end equipment – known as *Transparent Digital Transmodulators* (TDT) – for the consumer market. They are very different in complexity and concept from professional CATV head-ends. Nevertheless, the same user receivers (known in DVB jargon as *QAM-IRDs*) are valid for both CATV and SMATV-DTM (SMATV System A) systems.

2) Direct Distribution of QPSK signals

This is known as *SMATV System B* in ETSI terminology [3]. QPSK signals arriving from the satellite are delivered directly to the users in a very similar way to DTH installations. Two options have been considered:

- a) SMATV-IF, where the satellite QPSK signal is distributed along the cable at an IF of between 950 and 2050 MHz. Although this type of network has been installed in some parts of Europe, VHF/UHF distribution systems have been widely installed in the south of Europe; these cannot carry the higher frequencies required for SMATV-IF.
- b) SMATV-S, where the satellite QPSK signal is distributed in the extended S-band (230-470 MHz). Although this configuration is limited in capacity, it could be the optimum one for a transition period as it is adequate for both old and new distribution networks.

SMATV System A (transparent transmodulation) is similar to DVB-C in terms of modulation (QAM) and the range of frequencies that are used

for distribution to the users (i.e. VHF/UHF). On the other hand, SMATV System B (direct distribution) is similar to the DVB-S system, through its use of QPSK modulation and, nominally, its use of IF frequencies (as a variant, direct distribution may also be implemented in the extended S-Band range of frequencies).

6.1. SMATV reference channel model

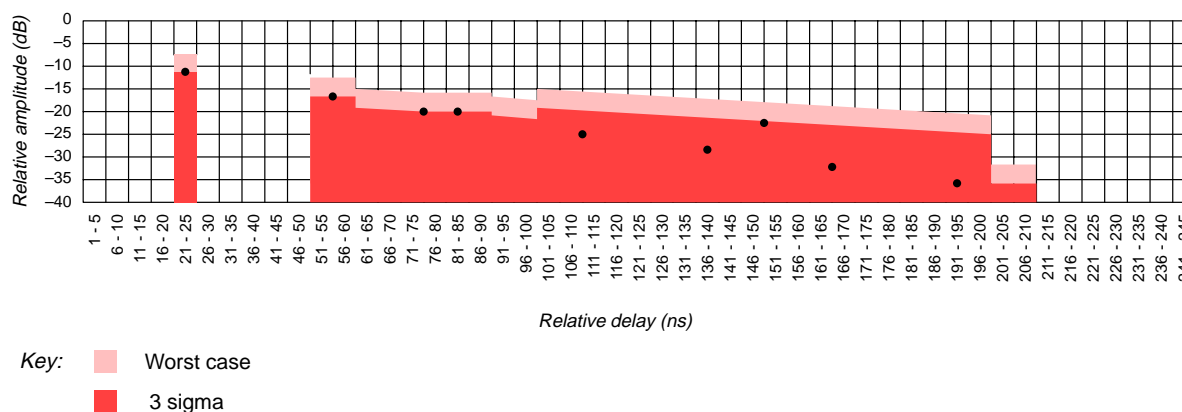
In order to test SMATV systems and to evaluate equalization requirements, the impulse response of a reference channel model in a SMATV distribution network has been derived – from the head-end to the user outlets. Based on computer simulations and theoretical analysis, the results have then been correlated with measurements and tests made at more than 300 outlets connected to around 20 real SMATV networks. This comprehensive set of measurements encompasses most types of SMATV systems, including combinations of parallel/cascade topologies with inductive/resistive technologies.

Fig. 10 illustrates the impulse response of the reference channel model of the SMATV network. The X-axis represents the echo delay between devices on consecutive floors and the Y-axis gives the echo attenuation. Results of studies recently carried out by the Euro-Image Project conclude that a similar model can also be applied to CATV networks and, therefore, the equalization requirements for user-IRDs are the same for both CATV and SMATV installations.

The reference channel model for most practical installations is marked with “3 sigma”⁸ and is represented in *Fig. 10* by dark shading. The light-shaded area on the diagram refers to the worst-case situation.

8. Three times the standard deviation (σ) from the mean conditions.

Figure 10
RF channel response of UHF and S-band SMATV distribution networks.



After intensive investigations, it was concluded that SMATV systems require equalization in nearly all cases where QAM signals are to be distributed. However, although the use of equalization is mandatory, it was concluded that simple equalization structures would be enough to cope with the short-term echoes that are generated in SMATV distribution systems with cable lengths of no more than several tens of metres.

Adaptive “blind” equalizers, composed of a symbol-spaced complex transversal FIR⁹ filter, were successfully tested by means of computer simulation. Half-symbol-spaced equalizers showed an even better performance. The minimum equalizer length should be of about 6 taps, while 8 to 10 taps could offer an additional margin to cope with longer echoes. The convergence time of the equalization algorithms were found to be very low – in the range of a few milliseconds.

Residual signal-to-noise degradation – for a BER of $2 \cdot 10^{-4}$ (before Reed-Solomon correction) – was evaluated by means of a computer simulation of 1000 different “3 sigma” SMATV channels, in the case of symbol-spaced and half-symbol-spaced equalizer configurations with 4, 5 and 6 taps. It was concluded that with 6 taps in the equalizer, the losses with respect to the ideal behaviour are smaller than 1.5 - 2 dB in all practical cases.

7. Other DVB systems

7.1. DVB-T

The DVB terrestrial system (DVB-T) is now evolving towards a commercial stage of development, as already achieved by the DVB satellite and

9. Finite impulse response.

cable systems. The draft baseline DVB-T system has already been produced.

For transmission via 8-MHz terrestrial channels, the practical upper limit on the bit-rate is about 24 Mbit/s; the actual useful bit-rate depends on the error correction and the type of modulation system used.

The baseband elements are based on the MPEG-2 coding system. A number of different configurations are possible, ranging from simple arrangements with a number of channels of conventional quality, to more sophisticated arrangements which involve multiple levels of coding and modulation.

The DVB-T signal is common with the other DVB systems. Nevertheless, an innovative modulation concept is used – OFDM – which is described in the article starting on page 39 [11].

7.2. DVB-MMDS

Another transmission system being studied by the DVB Project is Microwave Multipoint Distribution System (MMDS). The same philosophy is being applied to this system: a common payload and harmonized data container will be adapted to suit the physical characteristics of the MMDS transmission medium.

The DVB system for MMDS distribution is at the final phase and it is likely that it will comprise two configurations:

- DVB-MS, which will be common with DVB-S and will be suitable for frequencies above 10 GHz;
- DVB-MC, which will be common with DVB-C and will be suitable for frequencies below 10 GHz.



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8. Interoperability and interconnectivity

In the previous sections, the main elements which form the basis of each DVB system have been described. It can be seen that most of the key elements are common to all the DVB systems, particularly the video and audio source coding, the multiplex and framing structure, and the Reed-Solomon outer coding. Any divergences from the norm (i.e. “peculiarities”) mainly relate to the physical characteristics of the individual delivery medium, e.g. the modulation scheme used, the error protection required and the frequency range used. More information on this is given in [12].

This intelligent strategy allows the interconnection of different delivery media to provide an integrated broadcasting service, and also facilitates the achievement of economies of scale due to the fact that core elements of each DVB system are common. Another important aspect is that the DVB signals can transit through different transmission media in a seamless way, which greatly increases the availability of cost-effective solutions for digital television broadcasting.

9. Future trends

Extensive new television services are becoming available to the user, as a result of the rapidly-developing digital technologies. The current DVB systems for satellite, cable and terrestrial distribution of digital television will soon allow interactive capabilities which, based on different levels of user participation, may bring new business opportunities.

The definition of a specification for the DVB *interaction channel* (i.e. the return channel) will allow the implementation of an interactive return path to the service provider, thus enabling new types of broadcasting services to be provided. For example, a user of such interactive equipment would be able to participate directly in a programme from home.

The first interactive services will be of the *asymmetrical* type. This means that the user will receive the broadcast signal via a broadband channel, complete with information on the subject content of the service; at the same time, the user will be able to interact with the broadcaster, or programme provider, by sending low bit-rate messages along a narrowband return channel.

The DVB key to success – the monitoring of market needs and the commonality of sub-systems between different media solutions – will also be

retained during the process of defining the overall interaction channel. The production of suitable specifications for the interaction channel is being carried out by the Technical Module of the DVB through a specialized ad-hoc group, the DVB-RC.

Commonality with other systems being defined by international bodies, such as DAVIC¹⁰, are being assessed (see the article starting on *page 50* [13]). Priority has been given in DVB to the definition of the return channel through PSTN¹¹ and CATV networks. Technological projects, under the umbrella of the ACTS¹² programme of the European Union (DIGISAT, INTERACT, ISIS), will provide key results to support the definition of reliable technical specifications for satellite and terrestrial return-channel systems.

In conclusion, the DVB family of systems today allows the provision of digital broadcasting services via the most popular delivery media currently available; these systems satisfy the particular needs of the broadcasters, the users and, most crucially, the marketplace.

The future will bring new opportunities with the upgrading of DVB systems to include an interaction channel, thus allowing digital broadcasting to go “interactive” and hence give birth to the “active user”.

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